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EFFECTS OF CLIMATIC ENVIRONMENT

A Literature Review

By

C. B. ROUBICEK, R. T. CLARK and O. F. PAHNISH

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CATTLE PRODUCTION

A Literature Review

Section VIII

EFFECTS OF CLIMATIC ENVIRONMENT

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EFFECTS OF CLIMATIC ENVIRONMENT

Environmental studies with cattle, although generally quite limited, have been primarily concerned with the effects of high temperatures (5). Background information as well as actual experimental results have been summarized and the following section is a composite of these reports (10)(14)(39).

To those who have had an opportunity to compare the productivity of animals under various climatic conditions there is ample evidence to support the contention that productivity tends to be less, often startlingly less, in the hotter regions of the earth. Why lessened productivity is found in these regions is not clear. To a certain extent, and in some areas, the local patterns of culture have not developed a high degree of technical skill in animal husbandry, so that productivity naturally lags behind that of other places. But it is seldom sufficient to explain the differences which are observed. It seems inescapable that the climate in some way tends to lessen production. Climate could act in many ways to do this. The high degree of parasitism which occurs in most warm, humid areas, for instance, could easily induce marked fall in production. The poor protein and high fiber content of deceptively lush-looking forage plants of the same areas could be equally responsible. The precarious existence of forage in hot, dry areas is a continual threat to high production. But when full allowances are made for all these cultural and indirect climatic effects, an important portion of the fall in production still seems to be attributable to the direct action of hot climates on the animals (39).

Factors Affecting Body Temperature

Heat Dissipation

In all normal, warm-blooded animals, the body temperature remains constant within relatively narrow limits. This ability to maintain a constant temperature despite widely changing external conditions has been of great importance in establishing the superiority of the higher forms of animal life. Homothermy is attained by maintaining an equilibrium between the heat produced by the animal, together with any heat it may absorb from its environment, and the heat which it emits (14).

Animals, even when nonproductive and nonactive, have a huge "maintenance cost" to supply the energy for such obvious processes as circulation, respiration, excretion, muscle tension, and for many other processes not so obvious. The maintenance energy expense is eventually given off as heat (10).

This heat must be dissipated as soon as it is produced, else the body temperature rises above the normal level. A rise in body temperature of only 8° F. above normal is often quickly fatal, and the efficiency of the body machine deteriorates rapidly even with slight increases in body temperature.

When the environmental temperature is considerably below that of the body, the rate of heat loss in standing animals is mostly by radiation and convection, which may, together, be estimated with the aid of Newton's law of cooling. This law may be written as:

$$q = kA\ (t_1 - t_2)$$

in which q is the rate of heat flow between the body surface and the environment; A is the surface area of the body; t_1 and t_2 are, respectively, the temperature of the body surface and of the environment; k is the coefficient of heat transfer defined by the equation and determined experimentally, its numerical value depending on the units employed (10).

Newton's law of cooling indicates that the larger the surface area of a given body the greater the rate of heat transfer. The same holds for heat transfer by vaporization, convection, conduction, and radiation. Since, from geometrical considerations, the larger the body the smaller the surface area per unit volume, heat dissipation becomes more difficult as the body size of the animal increases. Conversely, in hot regions, where heat dissipation is difficult, the adaptational evolutionary trend must be for the body to be small and lean, giving it a large surface per unit volume, so as to have the largest possible rate of heat dissipation (10).

Newton's law of cooling was formulated for nonliving bodies. Warm-blooded animals have uniquely organismic or homeothermic methods of heat dissipation, the most important of which is moisture vaporization from the respiratory tract and skin. The rate of heat dissipation by vaporization is dependent on: (a) the surface area of the animal; (b) difference in vapor pressure between surface and of surrounding air (humidity); (c) rate of air movement which removes the humid air from the surface; (d) extent of respiratory activity (10).

The rate of heat dissipation by convection, that is, hot air near the skin replaced by cooler air which is in turn heated and moved away, is also proportional to the surface area of the animal, as indicated by the equation:

$$C = kA\sqrt{u}\ (t_1 - t_2)$$

in which C is convection rate; A is surface area; u, velocity of air, t_1 and t_2 are, respectively, the temperatures of the body surface and environment; k is the "unit convection conductance." The convection rate is, of course, accelerated by breeze, that is, by increasing the air velocity, u. But the convection (cooling) rate is increased only by the square root of the velocity (10).

The rate of heat dissipation by conduction, that is, by physical contact, as, for example, when an animal lies on a cold floor, is also proportional to the area through which the heat flows at right angles and to the temperature gradient.

The physiological feature of heat transfer from the body by conduction is that still air has an extremely low conductivity and that hair, feathers, and wool garments contain much air and are, therefore, excellent insulators. Hence the evolution of long, downy hair in species evolved in cold regions, and also the difference in the amount of subcutaneous fat in cold and hot environments. The lower the environmental temperature and the longer the hair coat, the greater the difference between the skin surfaces and of the hair coat (10).

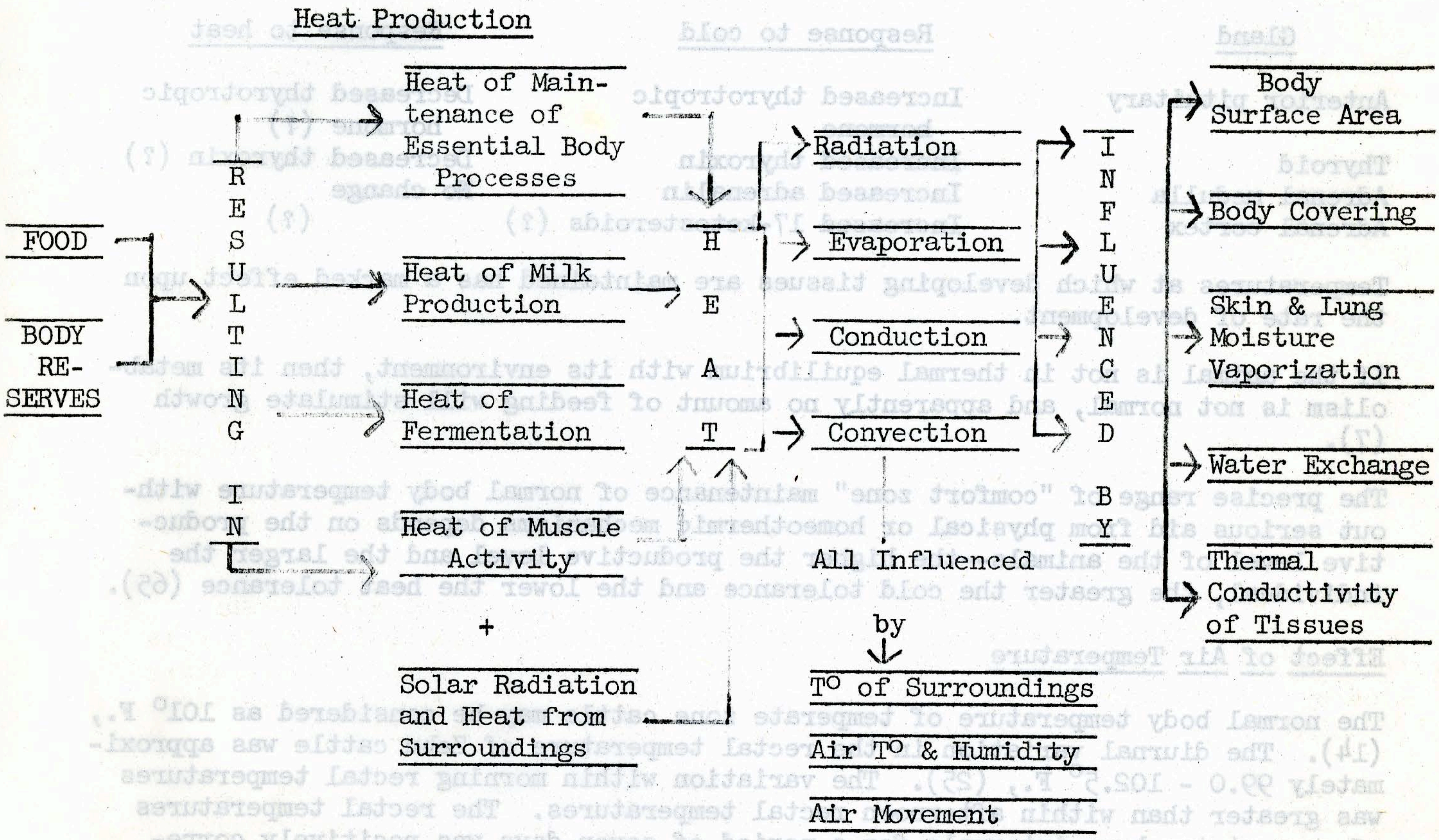
The rate of heat loss (or gain) by radiation is also proportional to the surface area of the animal but modified by a "configurational factor" (Lambert's law) since there is no heat loss by radiation between surfaces facing each other (10).

The change in form of the animal due to increase in weight during growth is quite different from the change in form of mature animals during fattening or fasting. The use of a prediction chart for estimating the surface area of an individual may involve an error as high as 10 percent of the true value (12).

When plotted against environmental temperature, vaporization at low air velocity gradually increases with increasing temperature from 18^{o} to 65^{o}, then more rapidly to 80^{o} F., when maximum vaporization is reached. But when vaporization at high velocity is similarly plotted the rapid increase in vaporization begins nearer 80^{o} F., and continues up to 95^{o} F. In other words, increasing air velocity shifts the vaporization curve to the right, extending the range of physiologically tolerable temperature to a higher environmental temperature (59).

The main routes of heat formation and heat loss have been shown by diagram (14):

Heat Production and Heat Loss



Effect of Energy and Metabolism

Nonlactating, resting, dairy cows produce heat at the rate of 400 to 500 calories per hour. Lactating cows produce about double this amount (10).

In domestic animals the metabolism per unit weight is very high at the beginning and declines with increasing weight. The rate of decline in metabolism per unit weight becomes less and less as the animal increases in weight, so that finally the metabolism per unit weight becomes practically constant (9). The metabolic level of an animal is more nearly proportional to the area of the body surface than to the body weight (36). The metabolic level of an animal may be characterized as the metabolic rate per $kg.^{3/4}$.

The ratio $\frac{\text{metabolic rate}}{\text{brain weight}}$ tends to be the same for small and large animals; the ratio $\frac{\text{metabolic rate}}{\text{body weight}}$ on the other hand, declines rapidly with increasing weight. This may imply the presence of a close physiologic interrelation between brain weight and metabolism (13).

Heat production also is influenced by the posture and activity of the animal. It is greater when the animal is standing than when it is lying, energy being required not only for the change in posture, but also to maintain the standing position (14). In a fasting beef animal, the energy expended in standing is about 9 percent greater than in lying. The increase is about 12 percent when the animal is fully fed. The energy requirement for getting up or down is about 11.2 kg. cal./1,000 pounds body weight. When a cow walks one mile the energy required, in addition to that required for maintenance and standing, is about 330 kg. cal./1,000 pounds weight.

There also appears to be an endocrine response to thermal stress (18)(40).

Gland	Response to cold	Response to heat
Anterior pituitary	Increased thyrotropic hormone	Decreased thyrotropic hormone (?)
Thyroid	Increased thyroxin	Decreased thyroxin (?)
Adrenal medulla	Increased adrenalin	No change
Adrenal cortex	Increased 17-ketosteroids (?)	(?)

Temperatures at which developing tissues are maintained has a marked effect upon the rate of development.

If the animal is not in thermal equilibrium with its environment, then its metabolism is not normal, and apparently no amount of feeding will stimulate growth (7).

The precise range of "comfort zone" maintenance of normal body temperature without serious aid from physical or homeothermic mechanisms depends on the productive level of the animals--the higher the productive level and the larger the individual, the greater the cold tolerance and the lower the heat tolerance (65).

Effect of Air Temperature

The normal body temperature of temperate zone cattle may be considered as 101° F., (14). The diurnal variation in the rectal temperature of Zebu cattle was approximately 99.0 - 102.5° F., (25). The variation within morning rectal temperatures was greater than within afternoon rectal temperatures. The rectal temperatures of cows at two-hour intervals for a period of seven days was positively correlated with direct sun temperatures taken four hours before rectal temperatures. It was suggested that afternoon temperatures might be more informative for diurnal purposes than morning temperatures.

TABLE I

The Effect of Air Temperature on the Body Temperature of Cattle (14)

Air Temperature (°F.)	Body Temperature (°F.)			
	Holsteins	Jerseys	Angus	Herefords
50	101.0	101.0	101.0	101.0
70		101.3		
75	102.3	101.5		
80	103.3	101.5		
81			102.9	102.2
84			103.0	102.8
85	103.8	103.1		
90		102.7	104.2	102.8
100		105.1	106.2	103.4

At air temperatures of 90° F., and above, studies of body temperature in Jerseys and Holsteins show a heritability of 28 percent and a repeatability of 53 percent (8).

In a study of ambient temperatures 0° to 105° F., on skin and hair temperatures of lactating Holstein and Jersey cows it was found that the temperatures of skin, hair, and air are widely apart at 0° F., (about 75° F., difference between skin and air temperatures, and about 45° F., difference between hair and air temperatures) and merge at 100° to 105° F., ambient temperature (60). At 0° F., ambient temperature, the hair surface temperature is about 50° F., in both Jerseys and Holsteins; the skin temperature is about 80° F., in Jerseys and 75° F., in Holsteins, with rather wide individual differences. At 103° F., ambient temperature the temperatures of skin and hair are also 103° F.

Calves cannot stand such high temperatures as cows (14). At 85° F., calves are already showing an abnormal rectal temperature of 103° F.

Of beef cattle exposed to high air temperatures and direct sun, Brahman cattle showed the most satisfactory ability to maintain their body temperatures and Angus the poorest. The ability to resist increase in body temperature was related to the amount of tropical blood present (51).

Effect of Humidity

A lowering of relative humidity while air temperatures are rising does not lower the rectal temperature of animals (14). It was concluded that a 1° F., rise in air temperature is responsible for from 13 to 15 times as great an effect on the body temperature as an increase of one percent in the relative humidity at the same air temperature.

Effects of Climatic Environment on Body Functions

The metabolic relationship to climatic environment has been briefly discussed. Climatic environment is probably a factor in most body functions but in many cases the relationship is difficult to determine with a required degree of exactness.

Heart Rate

Determining the heart rate of cattle accurately requires some precautions. Whether the animal is lying or standing makes a difference in the heart rate, and the mere fact that a person approaches the animal to determine heart rate will have an effect (14).

Feeding will increase the heart rate, and a low nutritional status (submaintenance) will cause a marked decrease (3). Although wide variations are noted between individual animals, the pulse rate of animals 5 to 18 months of age is generally between 80 and 90 beats per minute while for animals over 18 months of age it is generally between 60 to 70 beats per minute (14).

It appears that increased ambient temperature does not have a marked or consistent effect on heart rate. If the temperature does cause a change in heart rate it causes it to decrease unless the animal is exposed to the direct heat of the sun, then it may increase.

Respiration

Respiration in the field is observed at the flank of the animal. Under ideal conditions, the mean number of respirations per minute is 23 (4). The respiratory rate obeys van't Hoff's law, doubling for each rise of 10° C., air temperature, the data fitting the Arrhenius equation and giving a temperature coefficient (Q_{10}) of approximately 2 (14).

Breathing hot air in a cool environment did not increase the respiration rate or the depth of breathing, whereas breathing cool air in a hot environment markedly decreased the rate of respiration and increased the depth of breathing.

An increment of 0.4 gr./cu. ft. absolute humidity had the same effect as a 1° F. rise in air temperature. Both humidity and temperature have a greater effect on calves than on cows.

The increase in respiration rate in both calves and cows preceded the rise in body temperature. Panting occurred at respiratory rates of about 150 to 200 per minute with both cows and calves (14).

TABLE II

The Effect of Various Air Temperatures and Humidities on the Respiration Rate of Jersey Cows and Calves after Six Hours' Exposure at Different Temperatures and Humidities (14)

Air Temperature °F.	Humidity gr./cu. ft.	Respirations per Minute Cows	Respirations per Minute Calves
50-70	2 - 6	25	21
85	12	55	90
90	12	60	148
95	12	80	155
100	12	110	190
105	12	135	190
110	12	130	-
Percent increase over mean rate at 50 - 70° F. for air temperature of			
105	-	440	805
105	6	47	160
105	8	65	175
105	10	100	190
105	12	135	185
105	14	145	205
105	16	150	-
Percent increase over mean rate at 2.6 gr./cu.ft. and 50° - 70° F. for humidity of 14 gr./cu.ft.		480	876

TABLE III

Respiration Rates Per Minute of Jersey and Brahman Cattle at 45° F., 70° F., and 80° F. (57)

Air Temperature °F.	Radiation Level	Respiration Rate Per Minute Jersey	Brahman
45	1/4	28-45	17-21
45	1/2	22-43	16-17
45	3/4	47-57	17-18
45	Full	44-63	17-19
70	0	37-48	15-20
70	1/4	35-52	15-25
70	1/2	40-65	20-26
70	3/4	50-69	23-28
70	Full	56-90	30-41
80	0	55	26-33
80	1/4	49-58	32-40
80	1/2	62-82	33-47
80	3/4	60-92	32-55
80	Full	66-101	29-65

Respiration rate was not proportional to radiation intensity, except for a possible trend in the Brahmans (57).

TABLE IV

Respiration Rates Per Minute of Holstein Cattle at 70° F. and 80° F. (57)

Air Temperature °F.	Radiation Level	Respiration Rate Per Minute Black	White
70	0	34-52	34-41
70	1/4	38-51	21-66
70	1/2	36-56	28-58
70	3/4	37-57	36-70
70	Full	55-62	45-72
85	0	52-54	44-57
85	1/4	54-68	56-70
85	1/2	55-77	60-81
85	3/4	41-85	60-80
85	Full	84-97	66-96

There was no appreciable difference in respiration rate response between predominantly white and black Holsteins (57).

Increasing the environmental temperatures does cause a rise in respiration rate. There does seem to be some variation in the animal response; however, in field trials the factors other than temperature are not controlled and may also be involved in observed changes in respiration rate.

TABLE V

Average Number of Respirations Per Minute at Various Environmental Temperatures (14)

Breed	Respiration Rates Per Minute at the Following Temperatures (°F.) 51	66	73	84	97
Holsteins	28	30	44	92	107
Crossbred Holsteins	20	22	30	74	89
Zebus	23	23	27	35	46

TABLE VI

The Effect of Air Temperature on the Respiration Rate of Temperate Zone Tropical and Crossbred Cattle (14)

Shade Temperature °F.	Respirations Per Minute Hereford	Angus	Shorthorn	Afrikander	Shorthorn x Afrikander
80	49	65	92	48	39
83	71	74	112	54	39
90	85	95	141	59	42
94	98	116	112	71	48

It is only in the relatively narrow environmental temperature range, 60° to 80° F., that the respiration rate in Bos taurus rises exponentially with increasing environmental temperature in accordance with the van't Hoff rule. In Bos indicus the respiration rate is a better index of heat stress because the rise in respiration rates begins at a higher temperature and continues its exponential rise to a much higher temperature or radiation stress (57).

Increasing the atmospheric humidity at temperature levels from 75° to 100° increased the respiration rate in Jersey, Holstein, and Brown Swiss cattle at environmental temperatures above 80° F., and in Brahman cattle above 90° or 95° F. (35).

Spray caused a decided drop in respiration rates. Wet animals often had a respiration drop of 20 or more per minute (34).

The metabolism increases with the 0.6 power of body weight, as does surface area, but the ventilation rate increases with the 1.0 power of body weight. The oxygen removed from the inhaled air is about 4 percent at 100 pounds live weight and 2 percent at 1,000 pounds live weight (11).

There is evidence that the lung weight of beef breeds of temperate climates is less than that of other types of cattle (14). This may be a factor in explaining the respiratory behavior of temperate zone breeds as compared to Brahman and other similar breeds.

Heat Tolerance as Affected by Hair and Skin of Cattle

Solar radiation includes rays of three different wave lengths:

a. Long-wave rays - the infrared or heat waves
b. Rays of medium wave length - the light or white rays to which the eye is sensitive
c. The short-wave or ultraviolet rays, invisible to the naked eye

Both infrared rays and light rays are effectively reflected by white, yellow, or reddish-brown hair but not by black. Ultraviolet rays are effectively resisted by yellow, reddish-brown, and black hide colors. A white, yellow, or red coat with a dark hide is the ideal combination to render an animal resistant to the temperature and intense radiation of the heat and short-wave rays (7).

About 50 percent of solar energy reaches the earth in the "visible" range wave lengths from 4,000 to 7,000 millimicrons. The limit of short wave solar radiation is about 290 millimicrons; the long wave limit is about 2,500 millimicrons (57).

Within a coat color there is still variation in individual animal response to high temperatures.

Solid-black cattle showed very small differences in reflection, and these were attributed to the glossy coats or absence of a glossy hair coat. Varying degrees of heat tolerance of these black cattle are due to physiological functions related to heat disposal and not because of coat color (52). It also has been shown that Holstein cows with mostly black coloring maintain milk flow during the hot season more persistently than Holstein cows that are about half black and half white (38).

TABLE VII

The Mean Absorptivity to Solar Radiation of Hides of Different Colors (14)

Mean Absorptivity	White Zulu	Cream Simmental	Red Africander	Dark Red Sussex	Black Angus
(Percent)	49	50	78	83	89

Data have been presented on light reflectance (wave lengths 400 to 700 millimicrons) measured periodically with a recording spectrometer from the hair of Brahman and Brown Swiss cows during a 3- to 4-month confinement in a climatic chamber with the environmental temperature slowly increasing from 65° to 95° F. (58). The reflectivity of the hair of all cows increased, that is, changed color toward white, with the rise in environmental temperature. The rise in reflectivity with rising temperature was more rapid and occurred at a lower temperature in the Brahman that in the Brown Swiss cows, indicating a more sensitive adaptation of the Brahmans than Brown Swiss to increasing temperatures.

The amount of heat dissipated by a cow in conduction, convection, radiation, and vaporization is controlled in part by the vascular supply to the skin and by the rate of blood flow in the cutaneous blood vessels (17). Studies with Ayrshire calves and embryos indicate that the sweat glands appear to have a very poor blood supply, while the hair follicles and papillae are richly supplied.

Spindle-shaped myoepithelial cells with longitudinal myofibrils have been demonstrated in the sweat glands of Ayrshire and Zebu cattle (16). The cells in both breeds are similar in structure, location, and arrangement. It is, therefore, unlikely that any difference in function between the sweat glands of the two breeds can be ascribed to a difference in the myoepithelial cell layer of the glands.

In histochemical studies of bovine sweat glands of Zebu and Ayrshire cattle, positive reactions were obtained for ribonucleoprotein, arginine, and alkaline phosphatase. Negative reactions were obtained for desoxyribonucleoprotein and acid glycerophosphatase (66).

The chemical composition of the secretion of bovine sweat glands differs markedly from that of human eccrine or apocrine sweat glands in not containing detectable amounts of glycogen, lipids, and associated compounds of iron.

Although there is some indirect evidence indicating that cattle do sweat, the importance of this process in heat dissipation is not clear (14). Zebu cattle apparently have more of a tendency to sweat than do temperate breeds, but this difference does not appear to be a major factor in determining the breed differences for heat tolerance.

Buffaloes are more hyperthermic when exposed to direct solar radiation than either Shorthorn or Egyptian cattle. The Shorthorns were more affected by ambient heat than Egyptian cattle (2). The skin thickness of the buffalo is double that of the other breeds. In all animals, the thickness of the skin increased with age.

It also has been observed that black and piebald cattle have thin skin compared to cattle of other hair colors (31).

Shade and Water

Shade has been shown to cause a decrease in body temperature and respiration rate, especially if the animals were sprinkled with water before going under the shade (14)(30)(34). It is suggested that the shades should be constructed of aluminum or hay, 10 to 12 feet above ground, with 60 sq. ft. of shade per animal (30).

Water consumption by Brahman cattle was consistently less than by Hereford cattle. The average was 0.34 gallon less per 100 pounds live weight.

Cooling the drinking water to 65° resulted in less feed consumption and greater gain (28). Cool drinking water will increase the daily gain of animals in the feed lot 0.26 to 0.44 pounds. Warm water does not appear to have similar effects in cold weather (49).

	Lot 1 Cold Water	Lot 2 Warm Water
Hay per day (Pounds)	26.81	27.21
Silage per day (Pounds)	15.19	15.18
Daily gain (Pounds)	1.49	1.48

Fattening steers and calves fed and sheltered in the barn and having access to lots for exercise consumed the same amount of feed and made equal gain to those fed in the open.

Fattening steers given water warmed to 43 degrees consumed the same amount of feed and made the same gains as those receiving cold water.

Humidity

Increasing atmospheric humidity at temperature levels from 75° to 100° F. produced the following effects (35):

a. Increased the rectal temperature in Jersey, Holstein, and Brown Swiss cattle at environmental temperatures above 75° F., and in Brahman cattle above 90° or 95° F.

b. Increased the respiration rate in Jersey, Holstein, and Brown Swiss cattle at environmental temperatures above 85° F., and in Brahman cattle above 90° or 95° F.

Brahman cattle appeared to have dissipated a greater percentage of their total heat by evaporative cooling at high temperatures than European cattle (61). This was particularly true at high relative humidity levels.

Grazing Behavior

Studies of the grazing habits of cattle in hot climates show that there are differences between breeds. The grazing times of animals were related to the amount of tropical blood present, being greatest in the tropical cattle and least in the temperate breeds (14).

In feed lot studies in the Imperial Valley of California, a herd composed of Brahmans, crossbred Brahmans, Santa Gertrudis, Herefords, and Shorthorns was observed from April through October between 5 a.m., and 6 p.m. All of the cattle had access to a dry lot with adequate shade (27). In April and May all animals had four observable grazing periods. The first was from early morning until about 7 a.m. The time between 7 and 9 a.m., was spent in dry lot, and many of the Herefords and Shorthorns spent this time under the shade. The second grazing period was between 9 and 10:30 a.m.; from then until 1 p.m., the animals rested in the dry lot. All of them grazed a third time between 1 and 2 p.m., resting in the pasture about two hours thereafter. At 4 p.m., they grazed again, until 6 p.m. After May 16, many of the Herefords and Shorthorns missed this third grazing period and did not go out to graze until about 4 p.m.

In June, a difference in grazing habits of the various breeds began to develop. Almost all of the Herefords and Shorthorns were in the dry lot by 7 a.m., then the Santa Gertrudis came in, and last of all the Brahmans. All cattle were in by 9 a.m. Most stayed in the dry lot until 1:30 p.m., missing their second grazing period. About half of the cattle grazed for one-half hour; then all Herefords and Shorthorns came back to the shade, and many of the others lay down in the pasture. At 3 p.m., half of the Brahmans were grazing, but all Herefords and Shorthorns were still in the shade, and 80 percent of them were lying down. By 3:30 p.m., 90 percent of the animals were grazing, and at 4:30 p.m., all were grazing.

In August, all the animals were in the dry lot by 8 a.m., and their order of arrival was the same as in June. Most stayed in the dry lot until 1 p.m.; then 75 percent of the Brahmans and 20 percent of the Santa Gertrudis grazed for awhile. Some rested in the pasture while others came back to the dry lot. After 4 p.m., the Herefords and Shorthorns began going out to graze.

Grazing behavior studies with identical twins have shown that in a temperate zone climate is relatively unimportant in affecting the grazing pattern (19)(20)(21)(22)(24).

In the temperate areas, quantity and quality of herbage is more important that the differences in environmental temperatures. Dairy cows in Georgia do show irregular grazing habits (41) that are attributed to the increased temperature. In Oregon, a comparison of Brahman x Hereford crossbreds with Herefords indicates that variations in grazing activities were greater among animals of the same breed than between breeds (23).

Animals seem to adjust themselves to seasonal variations by changing the proportion of different food nutrients ingested. It may thus be inferred that feed is probably one of the more important factors in regulating the heat mechanism of animals (43).

Higher temperature resulted in lower intake of protein and fat. Maximum intake of carbohydrates was during the period of highest temperature.

Feeding trials indicate that roughage-concentrate rations produce less heat increment and greater gain than straight roughage in hot weather (30).

Temperature Effects on Blood Constituents

The influence of temperature on blood composition of cattle has been studied (6). The results were as follows:

a. No obvious changes occurred between 0° and 65° F., except possibly an increase in glucose level at lower temperatures.

b. On raising the temperature above 65° F., changes in some blood constituents appeared.

c. On raising temperature from 65° to 100° F., creatinine increased 100 percent, and carbon dioxide-combining capacity, ascorbic acid, and cholesterol were all reduced to less than half the level at 50° F.

d. No apparent disturbances in water, electrolyte and colloid concentration on increasing environmental temperature from 65° to 100° F. occurred.

e. The trends in plasma protein-bound iodine with changing temperature were too uncertain to permit interpretations in their bearing on thyroid activity.

These results indicate that care must be taken in interpreting the blood composition differences between breeds and locations since temperature may be one of the major factors affecting the blood composition.

The alkaline phosphatase was determined in a total of 299 cattle, using para-nitrophenyl phosphate as the substrate. The animals in this study included animals of the European and Brahman breeds, and some of their crosses (37).

a. The average of serum alkaline phosphatase activities of immature Brahman cattle is approximately twice that of the European breeds of the same age.

b. Crossbreds such as the offspring of crosses between the Brahman and the Hereford or Jersey, and the Santa Gertrudis breed, have phosphatase levels which fall between the European and Brahman breeds.

c. Although the alkaline phosphatase activity of bovine serum decreases with age, Brahman cattle continue to have the higher phosphatase levels.

d. Selection for dairy type as opposed to selection for beef type has little or no significant effect on the serum alkaline phosphatase. Sex has no marked effect.

e. Repeatability of the serum alkaline phosphatase within groups of Angus or Hereford bulls or Hereford steers is low, suggesting considerable effect of environmental factors.

f. In Hereford and Angus bulls, the phosphatase level appears to be negatively correlated with factors affecting rate of gain, efficiency of feed utilization, and feed intake.

Blood constituent studies were conducted with Red Sindhi-Jersey crosses (56).

Hemoglobin, hematocrite, plasma calcium, and plasma inorganic phosphorus levels are not appreciably altered by a six-hour period of exposure to hot conditions; therefore, since levels of these blood constituents do not indicate a response to thermal stress, these measurements, as presently taken, could not serve as suitable indexes of heat tolerance.

Nonpregnant, nonlactating cows have a plasma volume of 35 to 40 cc. per kg. body weight. They have 49.6 to 60.6 cc. of blood per kg. body weight (50). These plasma and blood volumes per unit body weight are significantly lower than rats, rabbits, dogs, sheep, and man.

A summary of blood constituent studies of tropical and temperate breeds of cattle leads to the following conclusions (14):

a. Tropical breeds of cattle have more erythrocytes per cu. mm. blood than temperate breeds. They also possess more leucocytes. The size of the red blood cells is smaller in tropical than in temperate breeds.

b. High hemoglobins are associated with high adaptability. The same is true of the specific gravity of blood, the serum p:ca ratio, and the number of erythrocytes. High temperatures cause an increase in the amount of circulating hemoglobin.

c. Sudden falls in temperature cause sharp rises in the leucocyte count of temperate cattle.

Measuring Heat Tolerance

Equipment for measuring animal reaction and assessing the climatic environment has been described in considerable detail (14)(32)(33)(39)(42)(59)(60)(62). The equipment required to measure accurately the temperature and physiological reaction in the animal is specialized and generally costly. There is reason to believe, however, that physiology studies are necessary together with performance data in order properly to evaluate climatic effects (39)(46)(47).

Heat Tolerance Evaluation

The "Iberia Heat Tolerance Test" has been suggested as a means for measuring cattle adaptability in the tropics with a minimum of time and equipment (54). The cattle to be tested are placed in a fenced field with water available. Days for the test should be bright and calm with temperatures at about 90 F. In the morning, cattle are carefully put into a chute, a few at a time, and their rectal temperatures are taken with a clinical thermometer. These cattle are then removed and more brought into the chute until all cattle have been processed. Then all cattle are returned to the field until afternoon when the process is repeated. This test is repeated on two different comparable days. Atmospheric temperature is recorded at the time rectal temperatures are taken. The animals must not be permitted to have shade and should be kept on grassed land.

The adaptability coefficient is computed by:

$$A = 100 - 10\ (BT - 101.0)$$

A = adaptability coefficient
101 = average normal body temperature
BT = average body temperature taken in the test
10 = conversion factor

Perfect efficiency would be 100.

Scale of Heat Tolerance for Cattle as Determined by the Iberia Heat Tolerance Test (54)

Breeding	Coefficient of Heat Tolerance
Purebred Brahman	89
1/2 Brahman, 1/2 Angus	84
3/8 Brahman, 5/8 Angus	84
Purebred Santa Gertrudis	82
1/2 Africander, 1/2 Angus	80
Purebred Jersey	79
1/4 Brahman, 3/4 Angus	77
Grade Hereford	73
1/4 Africander, 3/4 Angus	72
Purebred Angus	59

Analysis of heat tolerance data taken at the Iberia Livestock Experiment Farm showed no significant correlation between respiration rate and body temperature. Correlations between heat tolerance and performance as measured by birth weights, six-month weights, and five-year weights of cows and progeny were not significant (63).

Another index has been proposed that uses body temperature and respiration rate (4):

$$B.T./38.33 \quad N.R./23$$

When B.T. is the body temperature taken in the rectum in centigrade, 38.33 is the normal body temperature under most favorable conditions. N.R. is number of respirations per minute observed at the flank of the animal, and 23 is the mean number of respirations per minute under ideal conditions. The sum of "2" would therefore represent a high degree of adaptability.

Body temperature, respiratory rate, pulse rate, and blood hemoglobin values all have been used in determining adaptability (1). It also has been stated that adaptability of farm animals to tropical and subtropical zones is better assessed under shade and with normal husbandry conditions than by exposing the animals to direct sunlight (2).

Genetic Selection for Adaptability

The Zebu is unquestionably much more adapted to high environmental temperatures than are breeds evolved in temperate areas.

There are, however, many types of Zebu cattle with striking differences in conformation, color, and production (44). Galloway and yak breeds and crossbreds appear very well suited to arctic conditions (15). There are then, breeds and crossbred types adaptable to various climatic conditions in various parts of the world (45). Since environment may greatly modify the character expression of a given gene complex, it would appear wise to develop strains or breeds under conditions similar to those under which we expect them to function (64).

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